Geodesign the multi-layered water safety

PANAYIOTIS SOPHRONIDES, JOHN STEENBRUGGEN, HENK J. SCHOLTEN, MARIA GIAOUTZI

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Abstract

This paper aims to frame the multi-layered water safety concept in the context of a systematic, thorough, multidisciplinary and collaborative methodology for complex problems solving, i.e. geodesign. Multi-layered safety is an integrated flood risk management (FRM) concept based not only on flood probability reduction through prevention (layer 1), but also on consequences' minimization in the case of a flood through spatial solutions (layer 2) and crisis management (layer 3). It has been introduced in the Netherlands in 2009 following the European Flood Risk Directive adopted in 2007. In this study, the multi-layered safety is qualitatively assessed, demonstrating that it rather resembles a parallel system, and that collaboration is required to decide about the most desirable safety measures, which should not only be based on their economic efficiency but also on their social acceptability. In the light of these factors, we attempt to methodologically systematize the multi-layered safety concept by following the geodesign framework. The latter means that, through its implementation, understanding of the current situation of a particular area of interest, which in turn it may support, the allocation of weights regarding the three layers of the multi-tier safety concept is facilitated. Furthermore, the geodesign of the multi-layered safety shows that participation and interaction of the safety policy makers, as well as iterations for achieving maximum consensus between them concerning the more balanced safety measures, taking into account their economic efficiency, their impact on the environment, the local circumstances and the values of the people at place, are methodologically enabled.

KEYWORDS

Multi-layered water safety; Geodesign

1. INTRODUCTION

Flood risk management (FRM) in the Netherlands currently focuses on technical flood prevention measures such as levees and dikes (De Moel et al., 2014). However, in Europe flood management is moving towards an integrated risk management approach where measures about exposure and adverse consequences are considered (Büchele et al., 2006). This movement is motivated by the European Flood Directive (2007/60/EC) which urges EU member states to adopt a risk-based approach that takes into account potential consequences of floods next to their probability (Kellens et al., 2013). In the Netherlands, the multi-layered safety concept which consists of three layers, i.e. (1) prevention; (2) damage reduction via sustainable spatial solutions, and (3) preparation for emergency response, has been introduced as a reaction to the European Flood Directive in order to support a flood risk-based management approach (Ministry I & E, 2009). Nevertheless, the application of this concept is still in its infancy and a focus on preventive measures (layer 1) is obvious (De Moel et al., 2014).

The implementation of the multi-layered safety concept needs the combination of objectives and funding from various policy domains at different spatial scales and for several temporal horizons, the involvement of various disciplines and the collaboration between stakeholders with several interests and means (e.g. Potter et al., 2011). Required protection levels may vary between different areas, which may have different flood regimes. The optimal solution for Dutch flood safety can be a combination of measures from the three layers that jointly can minimize the overall flood risk (Ministry I & E, 2009). Without discussion and visualization of the impact of alternative water safety measures, their context cannot be understood so that they reflect local conditions and specificities. Furthermore, different stakeholders have different expectations regarding water safety. For instance, residents of a study area may aim to maintain a high level of flood security, irrespective of economic and environmental costs, technocrats may seek to preserve a significant level of water safety by keeping in mind the economic efficiency of the different measures, while public officials may see the same area as a vehicle to implement programs to achieve their political goals.

In the context of multi-layered water safety, a single methodological framework which determines the roles of different stakeholders, promotes dynamic visualization and communication of the current situation, enables the comprehension and evaluation of proposals and permits feedback in the necessary phases does not exist. In order to overcome the lack of methodology, the main goal of this study is to orchestrate the multi-layered safety concept in a geodesign framework-oriented decision-making process (Steinitz, 2012).

This study commences its mission by describing the main recommendations for flood safety and practices in Europe (section 2) followed by the Dutch perspective (section 3). In this context, the multi-layered safety concept is analyzed, attempting to demonstrate the need for a methodological framework which stimulates stakeholders' participation and active citizenship, experimentation and impact assessment, in order to reach optimal combination of safety measures tailored to the specific characteristics and conditions of an area of interest. The remainder of this paper is organized as follows: Section 4 provides definitions of geodesign and outlines geodesign framework and models. Section 5, firstly describes data underlying the multi-layered water safety concept and secondly it attempts to theoretically systematize this concept in a geodesign framework. Finally, section 6 presents the conclusions of this paper.

2. FLOOD SAFETY IN EUROPE

Floods are the most dominant natural hazards in Europe (Bakker et al., 2013). According to the European Environmental Agency (2010), only between 1998 and 2009, Europe suffered over 213 major damaging floods, which have caused some 1126 deaths, the displacement of about 500 000 people and at least € 52 billion in insured economic losses. However, by taking the right measures their likelihood can be reduced and their impacts can be limited. The need for developing comprehensive European water legislation was initially identified by the council in 1988, which has resulted in bilateral meetings of officials from France and the Netherlands to discuss the integration of European Water policy legislation (Bakker et al., 2013). Following an informal meeting in April 1995 between the Netherlands, France, Germany, the United Kingdom and Spain, a joint position paper was drafted which formed the basis for a wider consultation between water directors of all European Union (EU) member states. This process led to the adoption of Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, known as the Water Framework Directive (WFD). Although WFD deals with integrated water management, water quality and ecology (EU, 2000), the flood protection is not explicitly faced in it. Thus, a European approach to flood protection was put on the agenda resulting firstly in a Flood Action Programme in 2004 and later in the adoption of the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks known as the Floods Risk Directive (FRD) (Bakker et al., 2013). Introduced here are the FRD along with the Hyogo Framework for Action (HFA), which form two key recommendations for the protection of those at risk, and the main safety practices in Europe are explored.

2.1 The main recommendations for flood safety

Floods cannot be completely eradicated (Mostert & Junier, 2009) and for this, on the European level, attention has been moved from protection against floods to managing flood risks (e.g. Klijn et al., 2008; Twigger-Ross et al., 2009; Hecker et al., 2009; Vinet et al., 2008; Manojlovic et al., 2008). This fact is reflected in FRD, which entered into force on 26 November 2007. FRD is the first directive of the EU (Mostert & Junier, 2009) that deals with floods, requiring from the member states to perform a preliminary assessment of flood risks, mapping the flood extent, assets and humans at risk, prepare flood risk management plans for the regions under significant flood risk, and take adequate and coordinated measures to reduce this risk (EU, 2007). According to the directive, EU member states have to facilitate public participation, reinforcing public rights to access information and related measures about flood risks and to influence the planning process (ICPDR, 2012). In addition, EU member states have to coordinate the implementation of the FRD with the WFD. The driving force for this coordination is that physical flood protection infrastructures are some of the key drivers for determining the ecological status of waters with regards to hydro-morphological quality elements (Santato et al., 2013). In addition, a number of measures which focus on flood risk reduction can have multiple benefits for water quality, nature and biodiversity as well as regulate water flows and groundwater restoration in water scarce areas (Brättemark, 2010). In brief, preparation of river basin management plans under WFD and flood risk management plans under FRD are elements of integrated river basin management and thus their mutual potential for common synergies and benefits must be used.

FRM purports to reduce the likelihood and/or the impact of floods on human health, environment, cultural heritage and economic activity (Santato et al., 2013). In this context, EU member states should develop, periodically review and if necessary update plans for flood risk management with focus on prevention, protection and preparedness (EU, 2007). Prevention will be feasible via a suitable land use practice which prevents floods damage by avoiding construction of houses and industries in present and future flood prone areas, and by adapting future developments to the risk of flooding (EC, 2004). Furthermore, according to the European Spatial Development Perspective (1999), flood prevention in the major European river catchment areas can only be made effective through the imposition of explicitly defined conditions and intervention in land uses.

HFA along with FRD are two key policies for the protection of communities at risk (Bakker et al., 2013). “HFA for Action 2005-2015: Building the resilience of nations and communities to disasters” has been adopted in January 2005 by 168 governments during the World Conference on Disaster Reduction, held in Kobe, Hyogo, Japan and is about building resilience of nations and communities to disasters targeting to make the world safer from natural hazards substantially reducing the disaster losses, in lives and in the social, economic and environmental assets of communities and countries (UNISDR, 2007). HFA is essentially a global blueprint for disaster risk reduction, which provides guiding principles, priorities for action and practical means for achieving disaster resilience for vulnerable communities. It focuses on the development and strengthening of institutions, mechanisms and capacities to build resilience to hazards and it encourages the adoption of disaster risk reduction logic in sustainable development policies and planning as well as in emergency preparedness, response and recovery programmes (UNISDR, 2007). For the monitoring of the implementation of HFA, responsibilities are allocated to governments and also to regional and international organizations and partners in the United Nations International Strategy for Disaster Risk Reduction (UNISDR) secretariat. HFA is related to flood risk management, since floods are one of the main hazards, affecting annually millions of people all over the world (Bakker et al., 2013).

USE BY GOVERNMENT	BELGIUM (FLANDERS)	FRANCE	SWITZERLAND	NETHERLANDS	GREAT BRITAIN	ROMANIA	SLOVAKIA	HUNGARY	IRELAND	LITHUANIA	CZECH REPUBLIC	SLOVENIA	GERMANY	SPAIN	ITALY	FINLAND	AUSTRIA	LUXEMBOURG	POLAND	NORWAY	PORTUGAL	SWEDEN	LATVIA
Emergency Planning			*	*		*	*	*		*	*	*		*		*			*	*	*	*	*
Spatial Planning (Advisory)					*			*	*							*	*	*		*	*	*	*
Spatial Planning (Binding)		*	*			*				*			*	*	*				*				
Construction		*	*										*			*							
Awareness		*		*	*	*		*	*		*		*			*		*			*		
Insurance	*				*																		
Flood assessment/ management	*			*			*		*							*					*	*	

Table 1. Flood maps and their uses for flood safety in European countries (where information is available).

2.2 Flood maps and safety practices in Europe

Flood maps are developed by several institutions for a variety of purposes mostly used by the governments for emergency planning (e.g. evacuation) and spatial planning (De Moel et al., 2009). At the European level, some countries use spatial planning for advisory purposes and some other have binding legislation to employ flood hazard or risk information. The full potential of regulating land use in flood prone areas is often not reached as in many countries flood zones only serve as guidelines or there are practical problems associated with the implementation of binding rules (Santato et al., 2013; De Moel et al., 2009). Except from the planning purposes, flood maps are also utilized in raising awareness, in water management purposes, in flood assessments as well as in the insurance industry. The focus of different European countries in respect to flood safety for which flood maps are utilized is tabulated below (see Table 1).

3. THE DUTCH PERSPECTIVE TO FLOOD SAFETY

For over a millennium, people in the Netherlands have been both fighting against and enjoying the benefits of water from the sea, the major rivers Rhine and Meuse, precipitation and seepage of groundwater (De Lange et al., 2014; Ven, 1993). The Netherlands is considered as one of the safest deltas in the world, largely focusing on the flood prevention through its defense system. However, an evaluation of the water safety policy demonstrated that the country is not prepared for extreme flooding (Kolen et al., 2012). In addition, risk analysis for the Netherlands in 2008 (BZK, 2008) and 2009 (BZK, 2009) demonstrated that although a flood disaster is "highly unlikely"; it is the disaster type with the most catastrophic consequences in case of occurrence. For this, the multi-layered safety concept, which is currently the Dutch perspective to flood safety, is introduced and analyzed.

3.1 The multi-layered safety concept for flood risk management

As a response to the EU FRD, the Netherlands in its National Water Plan 2009-2015 has introduced the multi-layered safety concept, which bases on the widely adopted recommendations of both the FRD and the UNISDR's HFA. In essence, the multi-layered safety concept is a three-tier approach to flood risk management (Gersonius et al., 2011),which integrates measures for reduction of probability and mitigation of loss in a flood protection system (Tsimopoulou et al., 2013). Multi-layered safety reinforces flood protection and operationalizes flood resilience by distinguishing three safety layers: (1) prevention; (2) spatial solutions and (3) emergency response (Hoss, 2010; Tsimopoulou et al., 2013; Gersonius et al., 2011; Van Herk et al., 2014). It is both a risk-based and a resilience-based approach as it focuses not only on the reduction of the probability of flooding via preventive measures such as dikes reinforcement but also on the reduction of the consequences of flooding (e.g. human fatalities and economic losses) through spatial measures and preparedness for emergency response (e.g. emergency management plans) (Rijke et al., 2014; Hoss, 2010). Such a framework has been developed in Belgium's Flanders (Cauwenberghs, 2013). In USA and Canada (see for instance Lopez, 2009; Lopez, 2006 and Fraser Basin Council, 2008 respectively) similar approaches are used but called "multiple lines of defense" (Kolen et al., 2012).

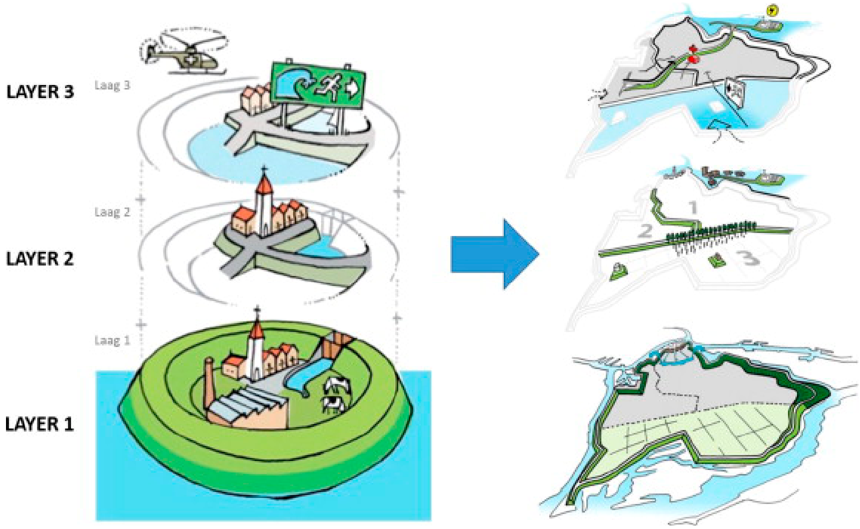


Figure 1. The three layers of the Dutch multi-layered safety concept which reduce the probability of floods (layer 1) and their consequences in case of occurrence (layers 2 and 3) (Rijke et al., 2014).

The three layers of the multi-layered safety (Figure 1), which forms an integrated flood risk approach, are presented below (Hoss, 2010; Tsimopoulou et al., 2013). The first two layers are physical measures while emergency response focuses on institutional (organizational) measures taken before the event (Hoss et al., 2011).

Layer 1: Prevention

This is about preventing rivers and seawater from inundating areas that are usually dry by constructing flood defenses or preventing high river discharges.

Layer 2: Spatial Solutions

These are pro-active measures focusing on the decrease of loss in the case of a flood occurrence by spatial planning, adaptation of buildings and protection of vital infrastructure. Solutions include location of urban and industrial land uses in areas with lower flood risk, raise of the constructions' ground levels etc.

Layer 3: Emergency Response

This focuses on flood emergency preparedness by setting the organizational framework of the emergency response as well as by developing evacuation plans, early warning systems, temporary physical measures such as sand bags and medical treatment.

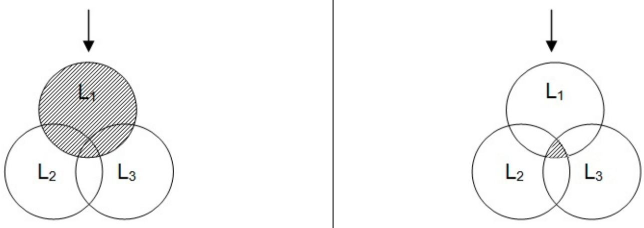
In the Netherlands, multi-layered safety is considered a shift from the past, where attention was traditionally paid on the first layer of flood prevention: the exploration of the potential of sustainable spatial planning and emergency preparedness, whose measures are intended to be tailored to local areas for minimizing the magnitude of the flood damage in case of such an event. However, multi-layered safety makes the task of water security more complex, as it is broader in scope and it requires multi-actor based work across multiple locations (Gersonius et al., 2011). While only Rijkswaterstaat (Directorate-General for Public Works and Water Management) and local waterboards are responsible for the first layer of dike rings, the second and third layers involve several parties including provinces, municipalities, safety regions and private parties, which call for a much higher level of coordination. Furthermore, the complexity of multi-layered safety lies in the need to account for future changes such as population increase or decrease, changes in economic and spatial developments.

3.2 Analysis of the multi-layered safety system

The Dutch shift from a predominantly prevention policy to multi-layered safety implies alteration of the flood risk management from a serial to a parallel system (Hoss, 2010). Furthermore, Jongejan et al. (2012) mention that multi-layered safety represents the relationships between the different phases or strategies as a parallel system rather than a serial system, which means that the different layers are not as weak as the weakest link fact that is falsely described by the safety chain concept. In this context, multi-layered safety requires interventions across its three layers to effectively reinforce the overall system's resilience to floods (Rijke et al., 2014; Gersonius et al., 2011). Hoss (2010), concluding that there will never be absolute safety, suggests implementation of multi-layered safety with respect to optimal allocation of resources instead of attempting to achieve maximum security at any price. Rijke et al. (2014) state that it is more efficient to invest in the layer(s) with the highest return on investment and to skip or minimize the use of the other(s).

$$MLS_{serial} = L_1 \cup L_{2/1} \cup L_{3/1} \quad (1)$$

$$MLS_{parallel} = L_1 \cap L_{2/1} \cap L_{3/1} \quad (2)$$



Venn diagram for a serial system

Venn diagram for a parallel system

where:

L_1: Failure of Layer 1 (prevention);

$L_{2/1}$: Failure of Layer 2 (spatial solutions) given the failure of Layer 1 (prevention);

$L_{3/1}$: Failure of Layer 3 (emergency response) given the failure of Layer 1 (prevention).

Figure 2. Failure of the multi-layered safety concept as a serial vs. a parallel system. (Adapted from Tsimopoulou et al., 2013).

For the description of how the multi-layered safety system will function as a serial vs. a parallel system in case of a flooding, equations (1) and (2) are used and the respective Venn diagrams are employed for visualization purposes (Figure 2). As layer 1 is about reducing the probability of occurrence of flooding through preventive measures, in the case of flooding, layer 1 de facto fails. In a serial system, if one of its components fails, means that the whole system immediately fails. In a parallel system this fails only if all its three layers fail. In case that one or two out of its three layers fail, the entire system does not fail. However, for multi-layered safety, neither the one nor the other system definition can be valid, while currently a definition regarding this has not been indicated (Tsimopoulou et al., 2013). Jongejan et al. (2012) justify the latter by the following paradigm: If a levee system were to fail, less or more humans could be saved through emergency response, but the immediate damages could not be undone, nor could crisis response bring the immediate flood victims back to life.

In multi-layered safety, if Layer 1 fails leading to a flooding, Layers 2 and 3 can minimize the consequences of this flood event. However, the measures taken in multi-layered safety should not only focus on the reduction of either the flood probability or the damage in case of flooding, but on both parameters simultaneously. The explicit definition of failure in each safety layer in the form of exceedance of certain thresholds can significantly contribute to the management of multi-layered safety systems, as it introduces safety classification added in a system by means of decrease of flooding probability; reduction of environmental and economic damage and minimization of human fatalities (Tsimopoulou et al., 2013).

3.3 The need to methodologically frame the multi-layered safety concept

The multi-layered water safety concept more closely resembles a parallel system in which Jongejan et al. (2012) mention that it is more cost-effective to invest in one component rather than dispersing the available budget over all of them. From an economic perspective, attention should be paid on how the different investment strategies affect the probability of adverse consequences, based on the rational assumption that smaller losses are desirable over greater ones. However, local conditions could lead to different optimal balances between measures corresponding to the three layers of this multi-tier safety concept, i.e. between measures for flood probability reduction and damage minimization in case of flooding.

Economically speaking, beyond low cost investments in damage mitigation measures, how effective could heavy investments in this direction be? In 2007, Taskforce was established to improve disaster preparedness (TMO, 2009), considering strong investments in emergency planning, evacuation routes and equipment. The purchasing and maintenance costs of a fleet of aerial rescue means (helicopters) is enormous, taking into account that they will be rarely used on average to save some people from their rooftops. But even in this case the huge economic impact of a flood disaster and the inevitable injuries and human fatalities are unavoidable. In this situation, the minimization of the probability of flooding would be the more efficient strategy. Another example is the case of a flooding in a densely populated area, where an additional investment in prevention is likely to yield a far greater return compared to an additional investment in loss mitigation measures (Jongejan et al., 2012). However, in the case of Dordrecht city in which historic buildings line the existing flood defenses, Hoss (2010), in a comprehensive assessment of the multi-layered safety concept where he has explored how the flood risks can be reduced, identified that the improvement of emergency response preparedness or the flood proofing of buildings could yield better compared to the strengthening of the flood defenses (flood probability reduction). This happens due to the relatively high costs of reinforcing the flood defenses, considering the relatively small size of the area protected by them (Jongejan et al., 2012).

Cost-benefit analysis can be applied for structuring complex decision problems (Arrow et al., 1996), including safety regulations. However, the ability of cost-benefit analysis to produce morally relevant outcomes has been challenged, particularly for matters related to health and safety, where factors other than costs and benefits influence humans' moral judgments (e.g. Slovic et al., 2004; Slovic et al., 1984; Fischhoff et al., 1981). Hence, the results of a strict cost-benefit analysis should not be binding for the agency heads (Arrow et al., 1996). In this context, the multi-layered safety should not be driven only by economic factors focusing on the estimation of some efficient balance between safety and return.

Since there is no one single multi-layered safety policy, a framework such as geodesign, which takes into account the roles and values of the people at place and the principles of sustainability in a collaborative and interactive process for making balanced decisions, is required. In this context, this paper purports to geodesign the multi-layered safety, having in mind that collaboration and maximum consensus between the involved stakeholders has to be achieved for deciding the most desirable, balanced and sustainable safety measures. In the following sections geodesign is introduced and applied in order to methodologically systematize the multi-layered water safety concept, following a characteristic script of geodesign.

4. METHODOLOGICAL FRAMEWORK: GEODESIGN

Geodesign needs collaboration, which in turn requires organization that asks for a framework around which tasks can be identified and linked (Steinitz, 2012). In this context, the methodology of this study, i.e. geodesign is introduced and framed.

4.1 Geodesign: Definitions

The design of land uses in the context of geographic space and natural environment is not a recent concept (Paradis et al., 2013). The latterly dubbed geodesign has its roots thousands of years ago, being an interdisciplinary process of place making, where design has been variably affected by surrounding geographies and natural conditions (McElvaney, 2012). Goodchild (2010) supports that geodesign is not new; he states that it represents a re-examination and probably a repurposing of a number of established fields. However, Miller (2012) argues that unlike the activity of geodesign, the term is relatively new and only a small number of geo-related businesses have utilized geodesign as part of their name.

Dangermond (2009) sees geodesign as a systematic methodology for geographic planning and decision making, which employs all the geographic knowledge (layers of information, measurements and analytic models) that users collectively build, maintain and import into a new interactive process where one can design alternatives and acquire geography-based feedback on the consequences of these designs in a timely manner. Flaxman (2010a,b) defines geodesign as “a design and planning method which tightly couples the creation of a design proposal with impact simulations informed by geographic context”. Steinitz (2012) simply specifies geodesign as changing geography by design, where design related processes are developed and applied towards changing the geographical study areas in which they are utilized and realized.

The desire to change geography goes beyond individual buildings, looking at the broader scale plans towards better understanding and effect on the landscape (Artz 2010, 21). For the practice of geodesign, interdisciplinary collaboration between the design professions, geographical sciences, information technologies and the people at place is a must (Steinitz, 2012).

Paradis et al. (2013) explore the various definitions of geodesign. They identify that the integration of geographic sciences and geo-spatial technologies with design, which facilitates digital geographic analysis to inform the design processes, is the fundamental characteristic of geodesign. Fully leveraging geography during the design process can result in designs that emulate the best features and functions of natural systems, where humans and nature are mutually benefited via a more peaceful and synergistic coexistence (Artz 2010b, 16). In this regard, Dangermond (2010) sees geodesign as "designing with nature in mind" (Artz 2010b, 6). Furthermore, Ervin (2011) mentions that "geodesign enhances the traditional environmental planning and design activities with the power of modern computing, communications and collaboration technologies, providing on-demand simulations and impact analysis to provide more effective and more responsible integration of scientific knowledge and societal values into the design of alternative futures".

4.2 Geodesign framework and models

Steinitz' framework for geodesign is illustrated in Figure 3 (Steinitz, 2012). It was previously known as framework for landscape planning (Steinitz, 1995); it employs six questions that can be answered by six models for the description of the overall geodesign process (Steinitz, 2012).

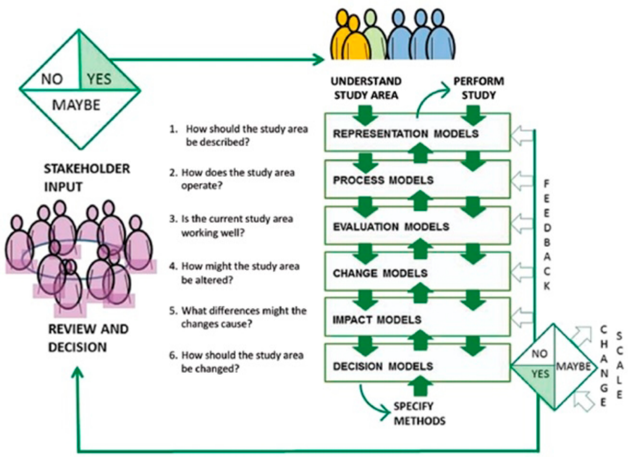


Figure 3. The geodesign framework (Steinitz, 2012).

The first three questions refer to the past and the existing conditions of the study area within a geographic context, while the last three are about the future more than the past and the present. The first three models, used for answering the first three questions, comprise the assessment process, while the last three models used comprise the intervention process respectively (Miller, 2012). The geodesign concept, through its six questions, provide a rapid, holistic, participatory, interactive and adaptive process for developing a more sustainable future (Dangermond, 2010). Furthermore, it enables the design of various alternatives, their evaluation in terms of impact on the natural environment as well as their utility to the human population, and selection and implementation of the alternative that is projected to achieve the best balance, thus supporting the development of the most educated and informed decisions about the future (Dangermond, 2009).

During a geodesign study, three iterations of the six questions of the geodesign framework (Figure 3) are explicitly or implicitly performed at least once before a decision towards implementation can ever be reached (Steinitz, 2012). In the first iteration where the questions are asked in a sequence from 1 to 6, the geographic study area as well as the context and the scope of the study are intended to be identified answering why the study should take place. In the second iteration, where the questions are asked in a reverse sequence, i.e. from 6 to 1, thus making geodesign decision-driven rather than data-driven, the methods of the study are intended to be selected and defined, simultaneously answering to the how questions. In the third iteration, the methodology designed by the geodesign team during the second iteration is carried out and, having data as a central concern, the study is implemented and results are provided. At this stage, the questions are asked from top to bottom, i.e. from 1 to 6, attempting to identify what, where and when.

Dangermond (2010) sees this iterative design/evaluation process as the way in which the human brain operates, i.e. try something, evaluate the results and move on. In order for the stakeholders to come to decisions, questions must be asked and answered and options for selection must be framed and deliberated. In short, the geodesign framework can be seen as a collaboration facilitator as well as a valuable support in the organization and solving of large and complex design problems, often at geographic scales, ranging from a neighborhood to a city, from the local to the national and even international level.

5. GEODESIGN THE MULTI-LAYERED SAFETY CONCEPT: THE CASE OF THE NETHERLANDS

Firstly, the information needs for the multi-layered safety concept in the Netherlands are explored. Afterwards, geodesign is theoretically implemented to present a framework for developing shared understanding of the current situation of an area of interest in terms of flood safety, as well as for achieving collaborative selection of the optimal multi-layered safety measures. The latter is accomplished by taking into account the values of the people at place, economic efficiency and environmental impacts of alternative safety measures in an attempt to achieve maximum consensus between the stakeholders.

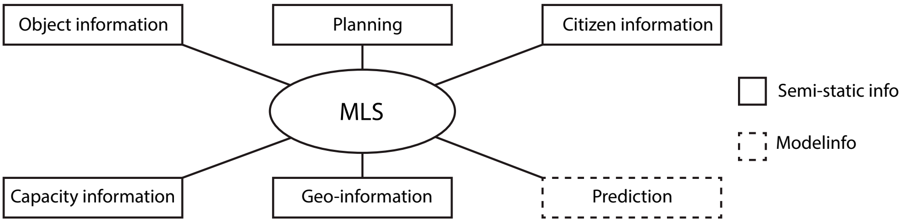


Figure 4. Overview of the information categories needed for the multi-layered safety concept (Adapted from ACIR, 2005).

5.1 Information needs

In order for a study area to be described, information is needed. The information requirements as described by ACIR (2005) for the multi-layered safetycan be determined as semi-static and model information. Furthermore, these information components are clustered into 6 different categories (Figure 4). However, when measures such as preventive organized evacuations are decided in the context of the emergency response layer, their implementation needs dynamic information. This is related to the (simulated) escalating flood and its effect on the incident location and the surrounding environment (geographical awareness), the capacity and the activities of the emergency response organizations to tackle it and normalize the situation.

In Table 2, an overview of data required for the multi-layered safety concept in the case of the Netherlands is provided. Almost all of these data have a spatial (geographical) component.

<table>
<tr><th>TEMPORAL NATURE</th><th>DATA</th><th colspan="2">DETAILS</th></tr>
<tr><td rowspan="2">SEMI-STATIC</td><td rowspan="2">Topographic data</td><td colspan="2">Top10NL: Open topographic data (Street networks; Railroad networks [Rail, metro and tram lines]; Water bodies [rivers, sea, lakes, etc.]; Building footprints; Terrain [grassland, arable land, etc.]; Design elements [noise barriers, trees, pylons, etc.]; Relief elements [land contour lines, sea depth lines, etc.]; Geographical and functional areas [neighborhoods, campgrounds, etc.]) that can be used at scales between 1: 5.000 and 1:25.000 throughout the Netherlands.</td></tr>
<tr><td colspan="2">BAG - Basic registration of Addresses and Buildings (In Dutch: Basisregistraties Adressen en Gebouwen): Open geodata about building footprints and addresses.</td></tr>
<tr><td></td><td>Elevation data</td><td colspan="2">AHN2 - Actual Height Data (In Dutch: Actueel Hoogtebestand Nederland): Open, detailed and precise elevation data (terrain, building and vegetation information) of 0.5 m x 0.5 m resolution. Digital Terrain Model (DTM) and Digital Surface Model (DSM) can be extracted from AHN2 providing terrain and objects' height information respectively.</td></tr>
<tr><td></td><td>Flood defenses' specifications</td><td colspan="2">Location, technical characteristics (e.g. capacity, cross-sections) of primary and regional flood defenses protecting from open (North Sea, Wadden Sea, rivers, IJsselmeer and Markermeer) and inland water (lakes, streams, canals) respectively. These include weirs, barrages, sluices and dams, which regulate water levels by water intake or releasing water when needed as well as dikes (floodgates or levees), natural sand dunes and storm surge barriers, which manage or prevent water flow into specific land regions. Topographic information about the flood defenses at scale 1:1.000 can be retrieved from DTB – Digital Topographic Database (In Dutch: Digitaal Topografisch Bestand).</td></tr>
<tr><td></td><td>Soil composition</td><td colspan="2">GeoTOP from TNO – Dutch Organization of Applied Scientific Research (In Dutch: Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek): Detailed three dimensional (3D) model of the subsurface of the Netherlands, which is divided into voxels of 100 m x 100 m resolution. Information regarding stratigraphy, lithology and uncertainty of the voxel appearance is included. It is currently available for the provinces of Zeeland and South-Holland. For the multi-layered safety concept, emphasis is placed on the composition of the primary and regional flood defenses.</td></tr>
<tr><td rowspan="3"></td><td rowspan="3">Water bodies data</td><td colspan="2">Water depths at different locations from the Normal Amsterdam Level (In Dutch: Normaal Amsterdam Peil [NAP]). NAP is also the Dutch point for altitude measurements (m).</td></tr>
<tr><td>Flow rates (m3/s) of water in natural and manmade open channels. Flow rate (m3/s) of the seawater.</td><td rowspan="2">The water services (In Dutch: Waterdienst) of Rijkswaterstaat and the regional waterboards can provide such information.</td></tr>
<tr><td>Cross-sectional characteristics of the water-bodies.</td></tr>
<tr><td></td><td>Precipitation and evapotranspiration data</td><td colspan="2">Time series of rainfall (mm) during a day, rainfall intensity (mm/h), evaporation (mm/day), transpiration (mm/day) and evapotranspiration (mm/day) for areas (ha) at different locations. This information can be derived from STOWA Meteobase, the foundation of applied water research (In Dutch: Stichting Toegepast Onderzoek WaterBeheer).</td></tr>
<tr><td></td><td>Sewerage system specifications</td><td colspan="2">Technical and geographical specifications of the system and its components (e.g. drains, manholes, pumping stations, screening chambers, storm overflows). Emphasis is placed on the collection of the storm water runoff. Regional waterboards and Rijkswaterstaat water services can provide such information.</td></tr>
<tr><td></td><td>Flood risk data</td><td colspan="2">Risk map (In Dutch: Risicokaart): Vulnerable objects exposed to flood hazards and guidelines for emergency preparedness in case of different inundation depths.</td></tr>
</table>

	Population	Numbers for every postcode district. (Derived from CBS - Central Bureau of Statistics (In Dutch: Centraal Bureau voor de Statistiek).	Inhabitants, density, growth, age, sex, disabled.
	Land uses	LGN6 - Nationwide Land Uses (In Dutch: Landelijk Grondgebruik Netherlands).	A grid file which distinguishes 39 land uses with a spatial resolution of 25 m x 25 m). Its main classes are urban, forest, water, nature and agricultural crops.
		Derived from CBS.	Land uses per municipality for different chronologies with their coverage in hectares (ha).
	Emergency capacity	Number and capacity of rescue means (ground and aerial) and emergency responders, classified per emergency organization (e.g. Fire brigade operational staff [professional and voluntary] provided by CBS). Location, number and capacity of emergency relief centers categorized by their function (e.g. medical aid, sheltering, catering, animal welfare), as well as by municipal area.	
	Financial indicators	Flood defenses.	Unit (construction, improvement and maintenance) cost, per type and function.
		Security care.	Material costs, per emergency response organization.
			Personnel costs (per capita spending), per emergency response organization.
MODEL	Prognosis data	Land-use forecasts. Flood forecasts based on different inputs and model parameters.	

Table 2: Flood maps and their uses for flood safety in European countries 2(where information is available).

5.2 Implementing geodesign on the multi-layered safety concept

In this study, geodesign is used as a theoretical framework in its conceptual form (Table 3) to shed light on involving stakeholders in the identification of the most desirable water safety measures, taking into account their socioeconomic and environmental impacts. The utilization of a geodesign framework purports to increase the effectiveness of the multi-layered safety concept, even though effectiveness is a broad concept which can include many aspects. In addition, through its models and iterations it intends to enable communication of stakeholders' values. In theory, by geo-designing the multi-layered safety concept, integration and exploration of ideas with direct evaluation at the same time is intended to be enabled. Furthermore, as geodesign is underpinned by trial and error logic, it increases the opportunity for experimentation and learning by doing (Steinitz, 2012).

GEODESIGN THE MLS	FIRST ITERATION (WHY?)	SECOND ITERATION (HOW?)	THIRD ITERATION (WHAT, WHERE, WHEN?)
1. How should the study area be described? *Representation models.*	What is the location of the Area of Interest (AoI)? How does the hydrologic system function in this AoI? What are the physical, economic and social activities in the AoI?	Where exactly is the study area and how is it bounded in hydrologic terms? Which data are needed? At what scale, classification, and times? From what sources? At which cost? How to be represented?	Acquire the required data (an overview is provided in Table 2). Analyze and visualize them over time and space using appropriate technology (multi-scale Geographic Information Systems [2D, 3D, 4D]). Organize them according to the needs of the three safety layers. Communicate them to the interested MLS parties using relevant (geo-) technology instruments (e.g. touch table [see below]).
2. How does the study area operate *Process models*	• What are the major hydrological processes in the AoI? How are these processes affected by precipitation and evapotranspiration, infiltration and percolation? • How are the surface and the sub-surface systems linked in the AoI? • How are the flood defenses functioning in the AoI? What is their capacity?	• Which hydrological processes should be considered in determining MLS policies and measures? • At what scale and for which time horizon should the safety measures operate? • What should be the level of complexity of the process models (for describing the AoI) that fit the purpose of the MLS study?	• Implement, calibrate and test the selected hydrologic models (stochastic; process-based models) for the AoI. Change the model parameters and run them several times. • Explain how the model outputs pinpoint the need to focus on one or more safety layer(s).
3. Is the current study area working well in terms of flood safety? *Evaluation models.*	Have high water depths been recorded in the AoI? Why? Are there currently problems with the functioning of the flood defenses? Why? Where? Are there developments in zones of high flood risks? How will they be tackled in the future spatial plans? Are the people at place aware about these problems? Are they prepared? Are the emergency agencies prepared to respond?	What are the evaluation criteria for the alternative safety measures corresponding to the three MLS layers? Economic? Legal? Societal? Environmental? What are the measures for evaluation of the success in terms of prevention (flood probability reduction), loss minimization through spatial solutions and emergency preparedness in the case of flooding?	Evaluate the flood safety condition of the AoI based on defined thresholds. Visualize and communicate the results. Explain how the local socioeconomic activities as well as environmental factors affect the flood safety in the AoI. Evaluate the current safety measures taken in the AoI, identify their effectiveness and classify them according to the three safety layers. Identify whether a reinforcement of the current measures or a shift is needed in the context of the MLS.
4. How might the study area be altered in order to meet the flood safety requirements? *Change models.*	In which of the three safety layers will the weights be placed? What are the alternative scenarios? Is visualization needed? How will the AoI meet the flood safety requirements in the future? Will it be a shift from the current practice? How?	What is the time horizon and scale(s) for the alternative safety measures? Are there any assumptions and requirements for them? What change model(s) will they be used to describe the future alternatives in terms of flood safety? Will the outcomes be simulated and/or visualized?	Example of alternative measures that can be visualized. Participants can propose more.

5. What differences might the changes cause in terms of cost- efficiency? *Impact models.*	What is the impact of the alternatives in terms of cost-efficiency? Are measures related to the reduction of flood probability more beneficial compared to measures related to consequences reduction in case of flooding? Why?	Are the economic impacts of the possible safety measures related to the three MLS layers regulated by legislation or regulations? How? Which impacts even if they are cost-effective should be assessed from a legal and/or environmental perspective?	Perform a cost-benefit analysis for the alternative measures corresponding to the different safety layers of the AoI. Identify and rank the most cost-effective. Visualize and communicate the results. Compare and explain the impacts of the measures corresponding to the different safety layers in terms of cost-effectiveness.
6. How should the study area be changed in order to meet the flood safety requirements, taking into account moral factors and values of the local society, cost-efficiency of the safety measures and the impact of the measures on the environment (principles of sustainability)? *Decision models.*	What is the main purpose of the study? Is it more efficient to invest only in the layer with the highest return in economic terms? Is it socially acceptable? Who are the major stakeholders and what are their positions, if known? Are there any binding technical and/or legal limitations for the AoI that must guide the MLS study? Are there any identified implementation difficulties for any of the measures related to the three layers of the MLS?	Who will make the decisions and how? What do they need to know? What will be the basis for their evaluation? Scientific? Cultural? Legal? Ethical? Combination of the previous? What should the decision makers consider as failure of the safety layers? Are there issues related to the implementation of the safety measures in terms of cost and technology?	Check whether the more cost-effective alternative measures, corresponding to the three safety layers of the MLS, are morally relevant and thus more likely to be socially acceptable. Check whether these measures have any side effects on the environment. Select a number of safety measures in a multi-disciplinary driven context, taking into account their economic efficiency, the values of the people at place and their environmental impacts and decide upon their suitability: • No, which implies more feedback; • Maybe, which means that further study at different temporal and spatial scales is required; • Yes, which drives to the presentation of the most suitable safety measures to the stakeholders for their decision and possible implementation.

Table 3: Theoretical implementation of geodesign on the Multi-Layered water Safety concept (MLS).

The results of framing the multi-layered safety in the context of a geodesign study are tabulated (Table 3). At the end of the process, the stakeholders can say no, maybe, or yes to the alternative safety measures. No, implies that the proposed safety measures do not meet their requirements; maybe can be treated as feedback, and calls for changes possibly in the allocation of the weights regarding the three safety layers; yes means implementation of the proposed safety measures. The latter will be used as data in the updates and future reviews of the multi-layered safety measures through the proposed framework. The route for coming into an agreement regarding the most suitable, desirable and balanced safety measures is not straight forward and normally non-linear, as many entries of different types and of different sources may be received, leading to revisit and revision of the decisions.

Moura (2015), based on her empirical study, mentions that the use of geodesign framework has proven to be a system in an open box that establishes steps, presents partial results, composes potential changes and choices, simulates alternative scenarios and possibilities, determines responsibilities, and limits of what is acceptable based on societal values and urge people to decide about their common future, employing a shared way of communications and ideas exchanging. In this line, it can be said that geodesign is not a linear process, as it contains feedback loops for model adjustments towards identifying optimal solutions. Stakeholders' involvement in the identification of the most favourable measures regarding the three layers of the multi-tier safety concept is needed to foster credibility in decision-making. In literature, some authors, including Batty (2013), Steinitz (2012) and Goodchild (2007), discuss how geo-technologies can support stakeholders' participation in geodesign. In particular, the potential of interactive geodesign tools in decision-making is increasingly acknowledged (Steinitz, 2012; Dias et al., 2013). For example, an interactive mapping device called "touch table" can be used as stakeholders' communication platform in the implementation of geodesign on the multi-layered safety concept, similar to previous studies (see Eikelboom and Janssen, 2015; Janssen et al., 2014; Arciniegas et al., 2013; Alexander et al., 2012). The added value service of a touch table, which includes for instance learning by experimenting, intuitive control and geo-spatial database availability, has been discussed in several articles (e.g. Pelzer et al., 2014; Pelzer et al., 2013; Eikelboom and Janssen, 2013; Arciniegas et al., 2011).

6. CONCLUDING REMARKS

In recent years there has been paid considerable attention to improving the flood protection in Europe and beyond. As a consequence, there was a growing need to share information and best practices in the field of flood risk management. In this context, the Netherlands has introduced the multi-layered safety concept for flood risk management, which is based on recommendations for flood protection such as the EU flood risk directive and the UNISDR Hyogo framework.

The multi-layered safety concept includes structural and non-structural measures representative of its three layers, which target to reduce the flood risk probability through prevention (layer 1), as well as the consequences in case of flooding, via spatial solutions and emergency response (layers 2 and 3). By analyzing a multi-layered safety system, it can be deduced that such a system resembles more a parallel than a serial one, as failure of the safety measures in one layer does not mean failure of the whole system. However, it is not exactly a parallel system, because when the preventive measures fail, the immediate consequences cannot be undone. The measures corresponding to layers 2 and 3 are able to reduce the damage, but not to completely eradicate it. Failure of the preventive measures is obvious when a flood occurs. But what is considered failure in layers 2 and 3 has to be explicitly defined, which will support the allocation of weights between the three layers of the multi-layered safety concept.

The goal to promote stakeholders participation and collaboration supporting decision making in regards to the most desirable and balanced water safety measures across different spatial and temporal scales has been achieved by theoretically orchestrating the multi-layer safety concept in a geodesign structure. A primary concern for the multi-layered safety concept is the inventory of the required data. Decisions, especially for matters related to flood safety, should rest on the firm ground of relevant and of high quality data. In this context, this contribution attempts to provide a first comprehensive overview of the data required for the multi-layered safety concept. However, questionnaire surveys with the participation of the involved to this multi-tier safety concept can shed more light regarding the information requirements of each safety layer. In this way, overlaps in terms of information needs between the three safety layers can be identified as well.

In order to develop and select optimal flood safety measures, all the stakeholders involved in the multi-layered safety concept have to develop awareness regarding the current water safety status in an area of interest. In particular, they have to comprehend the current functioning of an area of interest and also the way(s) in which flood safety is presently addressed. Furthermore, the stakeholders have to work together respecting each others values, considering local circumstances and searching for the most balanced and sustainable solutions. Cost-benefit analysis can extract the measures which can yield better from an economic perspective. However, in matters related to health and safety, human judgments are influenced not only by economic factors but also by ethical values. In this context, the systematization of the multi-layered safety concept, following the geodesign framework, creates surplus value for the local society, economy and environment through its different and iterative feedback-driven processes. The geodesign of the multi-layered safety concept motivates collaboration between the involved to the multi-layered safety parties without losing their identities. It underpins trial and error logic so that all stakeholders can assess the impact of the safety measures resulting from their own points of view. In this way, the stakeholders can identify overlaps in terms of the proposed measures which in turn can create maximum consensus between them, leading to the selection of the most desirable future water safety measures that considers their cost efficiency, their impact on the environment and the values of the people at place. But in order the geodesign of the multi-layered safety concept to be successful, it should be seen as useful by those working with it. If they intentionally deviate from the principles of this framework, the decisions, i.e. the safety measures can leave the stakeholders unsatisfied, because of which they will reject them.

Further research is needed towards transferring the implementation of geodesign on multi-layered safety from theory to practice. In particular, the geodesigned multi-layered safety concept should be experimented, tested and experienced in workshop settings and in different contexts for identifying optimal safety measures. Furthermore, during such workshops, technology driven tools, which empower society by enabling their participation in the decision-making, should be employed and assessed in the context of practicing geodesign in order to arrive at sustainable arrangements regarding water safety.

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